(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 December 2004 (16.12.2004)

PCT

(10) International Publication Number
WO 2004/109216 A2

(51) International Patent Classification⁷: F41H 5/04, 7/04

(21) International Application Number: PCT/US2003/027674

(22) International Filing Date: 2 September 2003 (02.09.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/281,732 28 October 2002 (28.10.2002) US

(71) Applicant: THE BOEING COMPANY [US/US]; P.O. Box 3707, M/S 11-XT, Seattle, WA 98124-2207 (US).

(72) Inventor: KOLLMANSBERGER, Ronald, B.; 1115 Inspiration Lane, Escondido, CA 92025-7928 (US).

(74) Agent: GALBRAITH, Ann, K.; The Boeing Company, P.O. Box 3707, M/S 11-XT, Seattle, WA 98124-2207 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 2004/109216 A2

(54) Title: BALLISTIC-RESISTANT MULTILAYERED ARMOR INCLUDING A STITCHED COMPOSITE REINFORCEMENT LAYER AND METHOD OF MAKING THE SAME

(57) Abstract: An armor is provided that includes an outer layer and a composite inner layer secured to the outer layer. The outer layer is made from a projectile-fragmenting material that is caplable of causing a projectile impacting it to break apart into a plurality of projectile fragments. The inner layer is formed by a stitched composite that substantially capture the projectile ftagments. The stitched composite includes at least one thread stitched through at least a portion of the inner layer's thickness. The armor is lightweight and highly ballistic-resistant, and suitable for use with any of a with range of military application, homeland defense situations, and non-military applications where excellent ballistic resistance is needed to protect individuals and/or various forms of equipment.

BALLISTIC-RESISTANT MULTILAYERED ARMOR INCLUDING A STITCHED COMPOSITE REINFORCEMENT LAYER AND METHOD OF MAKING THE SAME

FIELD OF THE INVENTION

[0001] The present invention relates generally to ballistic-resistant armor and more particularly to ballistic-resistant armor suitable for military combat vehicles.

BACKGROUND OF THE INVENTION

[0002] While in combat situations, military vehicles and their occupants are normally exposed to battlefield projectile danger such as armor-piercing, high caliber, high-velocity projectiles. As compared to handgun projectiles that are typically no more than 9-millimeter (0.354 inches) in caliber, military vehicles may, and often do, come under fire by 12.7-millimeter (0.50 inches), 14.5-millimeter (0.571 inches), 23.0-millimeter (0.906 inch) and even larger caliber projectiles traveling at velocities exceeding 4000 feet per second (1219.2 meters per second). Armor-piercing projectiles are especially dangerous in that an armor-piercing projectile is a type of projectile that is designed with a tip to penetrate completely through a vehicle's armor and then explode once inside the vehicle's interior.

[0003] When an unarmored or inadequately armored vehicle is struck by an armor-piercing projectile, significant injury or death of the vehicle's occupants can be caused by the projectile. In addition, the armor-piercing projectile may also render the vehicle itself inoperative by damaging one or more

IAP20 Rec'd PCT/PTO 12 JUN 2006

of the vehicle's critical operating systems (e.g., engine, communication, navigation, weaponry, etc.).

[0004] For these reasons, military vehicles are often provided with ballistic-resistant armor to prolong their viability and protect the military personnel therein from harm. For example, a common armor type used to shield military vehicles is a multilayered armor consisting of a ceramic outer layer and an unstitched composite inner layer. The ceramic tile outer layer is designed to cause fragmentation of a projectile upon impact therewith. The unstitched composite inner layer is designed to capture and thus prevent the fragments from penetrating the vehicle's interior.

[0005] A considerable composite thickness, however, is required to provide the unstitched composite inner layer with the capability of capturing the fragments of a battlefield projectile (e.g., an armor-piercing and/or large caliber projectile) fired by field artillery, anti-tank artillery, anti-aircraft artillery, among other sources that are typically encountered in military combat operations. Indeed, the sizeable but necessary composite thickness is such that the weight of the multilayered armor with unstitched composite reinforcement is driven by the composite thickness not by the axial structural loads (e.g., weight of weaponry, etc.) placed on the armor during use. In other words, a substantially thinner and thus lighter armor would suffice for supporting the axial structural loads if ballistic resistance was not a consideration. The weightiness of existing armors renders vehicles equipped therewith less mobile and transportable.

[0006] In addition, high material costs are another drawback associated with existing multilayered armors. Specifically, the fibers within the unstitched composite inner layer needed for providing sufficient ballistic

resistance against armor-piercing projectiles are costly. Thus, the total fiber costs can be especially significant given the thickness that is required for the unstitched composite layers.

[0007] Moreover, existing multilayered armors also do not have adequate damage tolerance to withstand multiple projectile impacts. After an initial projectile impact, the unstitched composite layers may stop the fragments thereof but will likely delaminate while doing so. Accordingly, little to no ballistic protection will be provided against subsequent projectiles striking the delaminated areas of the multilayered armor.

[0008] In many military combat situations, the element of surprise and/or the ability to deploy military equipment and personnel in a timely manner to worldwide "hotspots" can be extremely important. However, the weight of many types of ground vehicles, some of which is attributed to the heavy armors currently being employed, usually does not allow for convenient and practical air transport of the vehicles. As a result, heavy ground vehicles often must be transported instead via ocean-going and seafaring vessels.

[0009] Accordingly, a need remains for an armor structure that is capable of providing military vehicles with excellent ballistic resistance. Ideally, such an armor structure would be lightweight and thus enable the implementation of more lightweight, mobile and transportable military vehicles.

SUMMARY OF THE INVENTION

[0010] In one preferred form, the present invention provides an armor that includes an outer layer and a composite inner layer secured to the outer layer. The outer layer is made from a projectile-fragmenting material that is capable of causing a projectile impacting it to break apart into a plurality of projectile fragments. The inner layer is formed by a stitched composite that at least substantially captures the projectile fragments. The stitched composite includes at least one thread stitched through at least a portion of the inner layer's thickness. The armor is lightweight and highly ballistic-resistant, and suitable for use with any of a wide range of military applications, homeland defense situations, non-military applications where excellent ballistic resistance is needed to protect individuals and/or various forms of equipment.

[0011] In yet another preferred form, the present invention provides a method for making a ballistic-resistant multilayered armor for use with any of a wide range of military applications. In one embodiment, the method comprises the steps of: stitching at least one thread through at least a portion of the thickness defined by a plurality of stacked dry fiber fabric pieces; infusing the stitched fabric stack with a resin; allowing the resin to substantially cure; and using an adhesive to bond the resulting stitched composite to at least one ceramic tile. Preferably, the method further comprises installing the armor on a military vehicle.

[0012] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating at

least one preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The present invention will be more fully understood from the detailed description and the accompanying drawings, wherein:

[0014] Figure 1 is a cross-sectional side view of a ballistic-resistant multilayered armor according to a preferred embodiment of the present invention;

[0015] Figure 2 is a detailed view of a modified lock stitch disposed through a thickness of the armor's composite reinforcement layer shown in Figure 1;

[0016] Figure 3 is a detailed view of a standard lock stitch disposed through a thickness of a composite reinforcement layer of a ballistic-resistant multilayered armor according to another preferred embodiment of the present invention;

[0017] Figure 4 is a detailed view of a chain stitch disposed through a thickness of a composite reinforcement layer of a ballistic-resistant multilayered armor according to yet another preferred embodiment of the present invention; and

[0018] Figure 5 is a high level, process flow diagram of a method of making the ballistic-resistant multi-layered armor shown in Figure 1.

[0019] Corresponding reference characters indicate corresponding features throughout the drawings.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] Referring to Figure 1, there is shown a cross-section of a portion of a ballistic-resistant multilayered armor 10 according to one preferred embodiment of the present invention. Generally, the multilayered armor 10 includes an outer layer 12 and a composite inner layer 14 that are preferably secured to each other with an adhesive 16. The outer layer 12 includes a suitable projectile-fragmenting material that will cause a projectile 20 (e.g., an armor-piercing, high-velocity 12.7 or 14.5 millimeter projectile) impacting the outer layer 12 to break apart or fragment into a plurality of projectile fragments. To back-up and reinforce the outer layer 12, the composite inner layer 14 is formed by a stitched composite that substantially captures the projectile fragments thus preventing them from penetrating completely through the armor 10.

[0021] The multilayered armor 10 is lightweight, low-cost, and resistant to armor-piercing and other projectiles. Additionally, the multilayered armor 10 possesses sufficient structural integrity to support and carry axial loads (e.g., compression, tension, shear or various combinations thereof) arising from the armor 10 itself and/or other vehicle structures and accessories (e.g., weaponry, gun turrets, hatches, etc.). Indeed, the multilayered armor 10 maintains structural viability even under adverse conditions such as when a ground vehicle is traveling over rough or uneven terrain. These qualities and others make the multilayered armor 10 ideally suitable for installation on any one of a wide range of military and non-military implementations where excellent ballistic resistance is needed to protect individuals and/or various forms of equipment, such as ground vehicles, rotorcraft, fixed wing aircraft, artillery, banks, armored cars, etc.

[0022] The characteristics of the projectile (e.g., caliber, velocity, armor-piercing, etc.) that the multilayered armor 10 is designed to protect against will likely vary depending at least in part upon the identity of the combatant firing or launching the projectile. For example, different countries, terrorist organizations, etc. have different weaponry and projectile-firing capabilities. For these reasons, the particular configuration (e.g., dimensions, size, arrangement, etc.) of the multilayered armor 10 may vary, and will likely depend, at least in part on the specific type of projectile threat anticipated. Indeed, the multilayered armor 10 may be tailored or customized for combat with a particular country or terrorist group and/or their projectile-firing capabilities (e.g., caliber, velocity, armor-piercing, etc.). Accordingly, the multilayered armor 10 may be configured differently than what is shown and described herein without departing from the spirit and scope of the present invention.

[0023] The outer layer 12 of the armor 10 will now be discussed in more detail. The outer layer 12 is designed to break-up or cause fragmentation of projectiles striking the outer layer 12. Accordingly, the outer layer 12 comprises a suitable projectile-fragmenting material that is based at least in part on the specific type of projectile threat anticipated and the characteristics associated therewith.

[0024] Although various materials are possible for the outer layer 12, the projectile-fragmenting material preferably has a density less than about 0.250 pound mass (lbm) per cubic inch (6.92 gram/cubic cm). In an exemplary embodiment, the projectile-fragmenting material comprises a ceramic material having the capability to break apart at least a 50 caliber (12.7 millimeter) caliber projectile. Possible ceramic materials include, but are not limited to, Alumina (i.e.,

aluminum oxide), Silicon Carbide, and/or Boron Carbide. Of these ceramic materials, Alumina is the heaviest but least costly, whereas Boron Carbide is the most expensive but lightest. Accordingly, the determination as to the appropriate ceramic to be used for the outer layer 12 may be based at least in part on a tradeoff between cost and weight.

[0025] As shown in Figure 1, the outer layer 12 includes a plurality of ceramic tiles or plates 22 of suitable thickness 24 and hardness for fragmenting a projectile 20. In the process of fragmenting the projectile 20, the portion of the ceramic tile immediately adjacent to a projectile impact location will be shattered.

[0026] With further reference to Figure 1, the inner layer 14 is designed to completely, or at least substantially, capture the fragments of the projectile 20 after the projectile 20 has been fragmented or broken apart by the outer layer 12. To accomplish this feat, the inner layer 14 forms a stitched composite layer.

[0027] The inner layer 14 includes at least one thread 26 (e.g., needle thread with or without bobbin thread) stitched through at least a portion of its thickness 28 such that the inner layer 14 forms either a through-thickness or partial-thickness stitched composite layer. Preferably, and as explained in greater detail below, the stitching is performed on a dry fiber preform. The resin is preferably added after the stitching is completed so as to avoid the difficulties associated with stitching through either uncured “gooey” resin or through cured resin, which may be brittle and thus easily damaged.

[0028] The stitching may be provided via any one of a wide range of two-sided or single-sided stitching techniques now known in the art or that may

be developed in the future. In addition, the stitching may be provided via a stitching machine in an automated process, a robotic process, a manual process, or a combination thereof. Moreover, any one of a wide range of stitch types may be used for the multilayered armor 10. In one form of the inner layer 14, a modified lock stitch 30 is used for the armor 10 as shown in Figure 2. The modified lock stitch 30 includes a needle thread 32 and a bobbin thread 34. The bobbin thread 34 is disposed within the thickness 28 of the inner layer 14. The bobbin thread 34 is engaged with the needle thread 32 at about an outermost layer of the dry fiber preform.

[0029] In another embodiment, a standard lock stitch 130 may instead be employed within the inner layer 114, as shown in Figure 3. The standard lock stitch 130 includes a needle thread 132 and a bobbin thread 134 that are engaged at about a middle portion of the inner layer 114. Another common stitch type that may be used in yet another embodiment 214 of the present invention includes a chain stitch 230 (Figure 4). Unlike the standard and modified lock stitch types 30 and 130 which include both needle and bobbin threads 32, 132 and 34, 134, the chain stitch method 230 uses a single thread 232 in the manner shown in Figure 4. In still a further embodiment (not shown), tufting may be employed. As is known, tufting involves stitching a single thread through the dry fiber preform that will form the inner layer 14, looping the thread on the other side, and then securing the loop in place by infusing the preform with a resin. The resin infusion cycle 62 is described in greater detail below. In still yet a further embodiment (also not shown), a robotic one-sided/single-sided stitching system (e.g., a system developed by ALTIN Nähtechnik GmbH of Germany) that

enables one-sided sewing in a three-dimensional space may be employed to provide at least a portion of the inner layer's 14 thickness 28 with the thread 26.

[0030] Regarding thread type, any one of a wide range of thread types of suitable denier may be employed to provide the inner layer 14 with the stitching (e.g., 26, 30, 130, 230, etc.) including, but not limited to, an aramid thread (e.g., Kevlar® thread), a liquid crystal polyester thread (e.g., Vectran® liquid crystal polymer fiber), a Zylon® chemical fiber type of thread, a carbon thread, a fiberglass thread, a combination thereof, among other thread types. The thread type(s) chosen, however, is preferably compatible with existing standard stitching heads. In a preferred embodiment, the needle and bobbin threads 32 and 34 have a denier between about 400 and about 3600 and have a tensile strength of at least about 50 kip/square inch (ksi) (3,515.35 kgf/square cm).

[0031] The stitch density used in the inner layer 14 is preferably sufficient for the specific type of projectile threat anticipated and the characteristics associated therewith. Accordingly, the inner layer 14 may be provided with various stitch densities with the particular stitch density depending at least in part on the type of projectiles that the armor 10 will likely encounter.

[0032] In addition to thread, the inner layer 14 further includes a plurality of fibers such as woven fibers, non-woven fibers, braided fibers, and/or knitted fibers. The fibers may comprise any of a wide range of materials, such as fiberglass (E-glass, S-2 fiberglass, etc.), carbon fibers, aramid fibers (e.g., Kevlar® ballistic resistant fibers), a polyethylene fibers (Spectra® polyethylene fiber), a combination thereof, among others. Preferably, the fibers have a modulus of elasticity between about 8 million pounds per square inch (msi) (562,455.64 kgf/square cm) and 75 msi (5,273,021.62 kgf/square cm); a tensile

strength between about 200 kip/square inch (ksi) (14,061.39 kgf/square cm) and about 1000 kip/square inch (ksi) (70,306.95 kgf/square cm); and a density less than about 0.20 pound mass (lbm) per cubic inch (5.54 gram/cubic cm).

[0033] Each of the fibers used in forming the inner layer 14 may be arranged in a suitable number of plies or layers. The particular number of fibers, plies, and their respective angular relationships, however, will likely depend at least in part on the specific type of projectile threat anticipated and the predicted structural loads. For example, the angular relationships of the plies and/or the fibers within the plies may include a wide range of angularity combinations, such as 0, +/- 45 degrees, 60 degrees, 90 degrees, psuedo isotropic, quasi isotropic, a combination thereof, among other angular fiber arrangements.

[0034] By way of example only, the inner layer 14 can include all carbon fibers. However, other embodiments may include E-glass fiberglass, S2 glass, and/or carbon fibers in a variety of ratios. Other embodiments may also include an all fiberglass composite construction. As before with regard to the choice of ceramic material for the outer layer 12, the cost, weight and specific type of projectile threat anticipated may be considered when determining which type of fiber to use in the inner layer 14.

[0035] It should be noted, however, that the use of entirely all carbon fibers would not typically be suitable without the stitching (e.g., 30, 130, 230). Even though carbon fibers are about one-third (33%) lighter than typical glass fibers for the same volume, carbon fibers have rarely been used in ballistic-resistant armors because carbon fibers (when unstitched) do not absorb energy as well as fiberglass. Carbon fibers also have an improved modulus of elasticity that is about three to five times higher than typical glass fibers. Accordingly, the

present invention allows for the substitution of carbon fibers for fiberglass fibers to allow for even further weight reduction and improvement in ballistic resistance performance. For example, substituting carbon fiber for fiberglass in about one-half (½) of the layers of the inner layer 14 provided an approximately fourteen percent (14%) weight reduction as compared to an embodiment in which all fiberglass fibers were used. Or for example, weight savings of approximately twenty-four (24%) can be realized by using all carbon fibers instead of all fiberglass fibers.

[0036] To create a suitable matrix for the inner layer 14, the stitched dry fiber preform used to form the inner layer 14 is infused with a resin in a manner described in greater detail below and shown in Figure 5. Any one of a wide range of resins may be employed including, but not limited to, epoxies, cyanate esters, vinylesters, polyesters, thermoset resins, thermoplastic resins, polypropylene, among other resins types. Preferably, the resin selected provides a matrix having the following properties: a modulus of elasticity between about 100 kip/square inch (ksi) (7,030.70 kgf/square cm) and 1,000 ksi (70,306.96 kgf/square cm); a tensile strength between about 5 ksi (351.53 kgf/square cm) and about 25 ksi (1,757.67 kgf/square cm); and a density less than about 0.08 pound mass (lbm) per cubic inch (2.21 gram/cubic cm). Accordingly, the matrix created with the resin allows for the transmission of forces between the fibers, holds the fibers in their proper orientations, protects the fibers from the surrounding environment, and arrests crack propagation between the fibers.

[0037] The inner layer 14 may be secured to the outer ceramic tile layer 12 by any one of a wide range of conventional means including but not limited to mechanical fasteners (e.g., screws, bolts, rivets, etc.), adhesives

(chemical adhesives, room-temperature curing adhesives, elevated-temperature curing adhesives, film adhesives, paste adhesives, two-part epoxies, etc.), thermal bonding, cobonding, and combinations thereof, among other suitable processes. In a preferred embodiment, the inner and outer layers 12 and 14 are bonded to each other with room-temperature or elevated-temperature curing adhesive 16 that has the following properties: a modulus of elasticity between about 100 kip/square inch (ksi) (7,030.70 kgf/square cm) and 1,000 ksi (70,306.96 kgf/square cm); a tensile strength between about 5 ksi (351.53 kgf/square cm) and about 25 ksi (1,757.67 kgf/square cm); and a density less than about 0.08 pound mass (lbm) per cubic inch (2.21 gram/cubic cm).

[0038] The ballistic resistance performance of the inner layer 14 of the multilayered armor 10 has been tested and analyzed via impact tests, pull-off tests, ballistic tests, and shoot-through tests undertaken on test panels comprising various composite material and stitching variables. In one series of testing, a resin film infusion (RFI) process was used to create six (6) fiberglass fiber only panels and six (6) fiberglass-carbon fiber panels. Each of the twelve (12) composite test panels were substantially uniform in terms of thickness and resin content. Each test panel included a CoorsTek alumina armor tile bonded at about its center area and either no stitching, partial-depth stitching, or full-depth stitching. Accordingly, each test condition utilized two substantially identical test panels.

[0039] The ballistic projectiles used for the testing were 50 caliber armor piercing incendiary projectiles which impacted the test panels at approximately 2600 to 2700 feet per second (792.8 to 822.96 meters per second). The test results clearly showed that both the partial-depth and full-depth

stitching prevented the massive delamination that occurred in all four of the unstitched panels (i.e., the two fiberglass fiber unstitched panels and the two fiberglass-carbon fiber unstitched panels). Indeed, there was little to no delamination within the partial-depth and full-depth stitched test panels other than within the area immediately proximate to the projectile impact location such that the stitched test panels would provide at least some ballistic resistance projection against subsequent projectile striking adjacent a previous projectile strike. In contrast, the unstitched test panel would provide little to no protection against subsequent projectiles striking adjacent to the impact location of a previous projectile because the projectile strike will cause massive delamination and structural integrity loss in the area proximate to the projectile impact.

[0040] The test results also clearly showed substantial improvements in ballistic resistance, durability and damage tolerance for the test panels that employed stitching through at least a portion of the thickness. The test results further showed that the partial-depth and full-depth stitching provided a significant increase in the structural integrity of the test panels when compared to that of the equally-thick unstitched test panels. Accordingly, thinner stitched laminates can provide ballistic resistance comparable to that of known armor recognized in the art while using less composite material, which in turn allows for the realization of considerable weight reductions and material cost savings.

[0041] In another form, the present invention also provides a method 50 for making the ballistic-resistant multilayered armor 10. In one embodiment, the method 50 comprises the following steps.

[0042] First, a dry fiber fabric material (e.g., woven fabric, non-crimp fabric, knitted fabric, braided fabric, etc.) is selected or fabricated at step 52, as

the case may be. The dry fiber fabric material preferably has characteristics (e.g., fiber diameter, fiber length, fiber size, fiber material, fiber orientation, fiber cross-sectional shape, etc.) based at least in part on the design requirements (e.g., weight, specific type of projectile threat anticipated, costs, loads, etc.) of the particular application in which the multilayered armor 10 will be used.

[0043] The dry fiber fabric material is cut into pieces at step 54 wherein each piece has a shape defined for the corresponding ply being created with the cut fabric piece. At steps 56 and 58, the fabric pieces are stacked and then stitched together using any one of a wide range of stitching techniques (e.g., 30, 130, 230, automated, manual, combination thereof, etc.) according to the design requirements (e.g., stitch type, stitch density, thread type, etc.), thus creating a dry fiber preform.

[0044] Next, the dry fiber preform is placed on a cure tool or bond jig at step 60 and thus readied for a resin infusion process 62 (e.g., vacuum assisted resin transfer molding, resin film infusion, resin transfer molding, resin injection molding, among other common resin infusion processes). During the resin infusion process 62, which may include autoclaving or oven curing, the dry fiber preform is wetted or infused with a suitable resin 63 to provide further and sufficient stabilization of the stitched fabric stack. After the resin 63 has been allowed to sufficiently cure, the completed part (i.e., the inner layer 14) is inspected for quality requirements.

[0045] If acceptable, the ceramic tiles 22 forming the outer layer 12 are then bonded to the outer surface 18 (Figure 1) of the of the inner layer 14 at step 64. Preferably, a room-temperature or elevated-temperature curing adhesive 16 is used to bond the inner layer 14 to the outer layer 12. In other embodiments,

however, the resin 63 may be used to bond the inner layer 14 to the outer layer 12 instead of the adhesive 16.

[0046] The multilayered armor 10 may now be installed on a military vehicle or other equipment as needed. Alternatively, the inner layer 14 may be bonded to the outer layer 12 at a later stage to prevent assembly line damage problems.

[0047] Accordingly, the present invention integrates composite fiber preform stitching technology and ballistic-resistant composite structural configurations in a unique and innovative way to provide a multilayered armor 10 that is lightweight and that provides exceptional ballistic resistance to armor-piercing and other battlefield projectiles. The stitching improves the ballistic resistance of the armor 10 while allowing for considerable weight savings through material reduction, while still improving durability, damage tolerance and maintaining ballistic resistance comparable to that of known armors recognized in the art. The armor 10 also has sufficient structural integrity to maintain structural viability even under adverse conditions (e.g., while the vehicle is traveling over rough, uneven, bumpy terrain).

[0048] By permitting weight reductions while maintaining current ballistic protection for a vehicle's systems and crew, the present invention enables the implementation of more mobile and transportable military vehicles. Indeed, the present invention provides sufficient weight reduction to render air transport more convenient, practical and less expensive than what is currently possible with known armors recognized in the art.

[0049] Presently, most armors are either of the heavy metal type construction or multilayered structure wherein ceramic tiles are reinforced or

backed by a very thick unstitched composite. By combining stitched composites with ceramic tiles, however, the present invention is able to provide improved ballistic resistance with minimal weight. The full-depth or partial-depth stitching, as the case may be, substantially increases the structural integrity of the composite reinforcement layer 12 such that ballistic resistance comparable to that of known armors can be achieved with far less composite material being needed. In doing so, the present invention allows for considerable weight and material costs reductions. Further, ceramic tiles and stitched composites require far less maintenance as what is required with metallic armors.

[0050] Compared to an unstitched composite layer of substantially equal thickness, the composite inner layer 14 has considerably higher damage tolerance and substantially improved residual structural integrity after ballistic impacts. Accordingly, the multilayered armor 10 provides ballistic resistance projection against projectiles subsequently striking adjacent to a previous projectile strike and thus improves the long term survivability of military equipment, vehicles, artillery, etc. equipped with the multilayered armor 10.

[0051] It is anticipated that the invention will be applicable to a wide range of military and non-military applications and equipment (e.g., but not limited to, ground vehicles, tanks, anti-tank artillery, anti-aircraft artillery, field artillery, ships, seafaring vessels, helmets, portions of rotorcraft, fixed wing aircraft, banks, armored cars, among others). Accordingly, the present invention should not be construed as being limited in application to only one specific type of military or non-military application, as the invention could be applied in any implementation where excellent ballistic resistance is needed to protect individuals and/or various forms of equipment.

[0052] The description of the invention is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. Thus, variations that do not depart from the substance of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. An armor comprising:

an outer layer configured to fragment a projectile impacting the outer layer into a plurality of projectile fragments; and

a composite inner layer engaged with the outer layer, the composite inner layer operating to substantially capture the projectile fragments, the composite inner layer having at least one thread stitched through at least a portion of its thickness.

2. The armor of claim 1, wherein the armor is configured to support an axial load produced at least partially by the armor and by at least one other component.

3. The armor of claim 1, wherein the composite inner layer comprises a plurality of carbon fibers.

4. The armor of claim 1, wherein the composite inner layer comprises a plurality of fiberglass fibers.

5. The armor of claim 1, wherein the composite inner layer comprises:

a plurality of carbon fibers; and

a plurality of fiberglass fibers.

6. The armor of claim 1, wherein:

the composite inner layer comprises a plurality of fibers; and

the plurality of fibers comprise at least one of a carbon fiber, a fiberglass fiber, an aramid fiber, or a polyethylene fiber.

7. The armor of claim 1, wherein the outer layer comprises at least one ceramic tile.

8. The armor of claim 1, wherein the armor is configured for installation on a military ground vehicle.

9. A military vehicle comprising an armor, the armor comprising:

an outer layer configured to fragment a projectile impacting the outer layer into a plurality of projectile fragments; and

a composite inner layer engaged with the outer layer, the composite inner layer comprising at least one thread stitched through at least a portion of its thickness, the component inner layer being configured to substantially capture the projectile fragments.

10. The military vehicle of claim 9, wherein the armor is configured to support an axial load produced at least partially by the armor and by at least one other vehicle component.

11. The military vehicle of claim 9, wherein the composite inner layer comprises a plurality of carbon fibers.

12. The military vehicle of claim 9, wherein the composite inner layer comprises a plurality of fiberglass fibers.

13. The military vehicle of claim 9, wherein the composite inner layer comprises:

a plurality of carbon fibers; and

a plurality of fiberglass fibers.

14. The military armor of claim 9, wherein:

the composite inner layer comprises a plurality of fibers; and

the plurality of fibers comprise at least one of a carbon fiber, a fiberglass fiber, an aramid fiber, or a polyethylene fiber.

15. The military vehicle of claim 7, wherein the outer layer comprises at least one ceramic tile.

16. An armor comprising:

first means for fragmenting a projectile into a plurality of projectile fragments; and

second means for substantially capturing the projectile fragments, and being secured to the first means such that the projectile fragments impact the second means after impacting the first means.

17. A method of making an armor, the method comprising:

providing a composite layer having stitching through at least a portion of its thickness;

providing a projectile-fragmenting material; and

securing the projectile-fragmenting material to the composite layer.

18. The method of claim 17, wherein securing the projectile-fragmenting material to the composite layer comprises using an adhesive.

19. The method of claim 17, wherein providing a composite layer having stitching through at least a portion of its thickness comprises:

stitching at least one thread through at least a portion of a thickness defined by a plurality of stacked dry fiber fabric pieces;

infusing the stitched fabric stack with a resin; and

allowing the resin to substantially cure.

20. The method of claim 19, further comprising:

cutting a dry fiber fabric material into a plurality of pieces; and

stacking the plurality of pieces.

21. The method of claim 19, wherein stitching at least one thread through at least a portion of a thickness defined by a plurality of stacked dry fiber fabric pieces comprises using a stitching machine.

22. The method of claim 19, wherein each dry fiber fabric piece comprises a plurality of carbon fibers.

23. The method of claim 19, wherein each dry fiber fabric piece comprises a plurality of fiberglass fibers.

24. The method of claim 19, wherein each dry fiber fabric piece comprises:

a plurality of carbon fibers; and

a plurality of fiberglass fibers.

25. The method of claim 19, wherein:

each dry fiber fabric piece comprises a plurality of carbon fibers; and

the plurality of fibers comprise at least one of a carbon fiber, a fiberglass fiber, an aramid fiber, or a polyethylene fiber.

26. The method of claim 19, wherein the projectile-fragmenting material is secured to the composite layer with the resin.

27. The method of claim 17, wherein the projectile-fragmenting material comprises at least one ceramic tile.

28. The method of claim 17, further comprising installing the armor on a military vehicle.

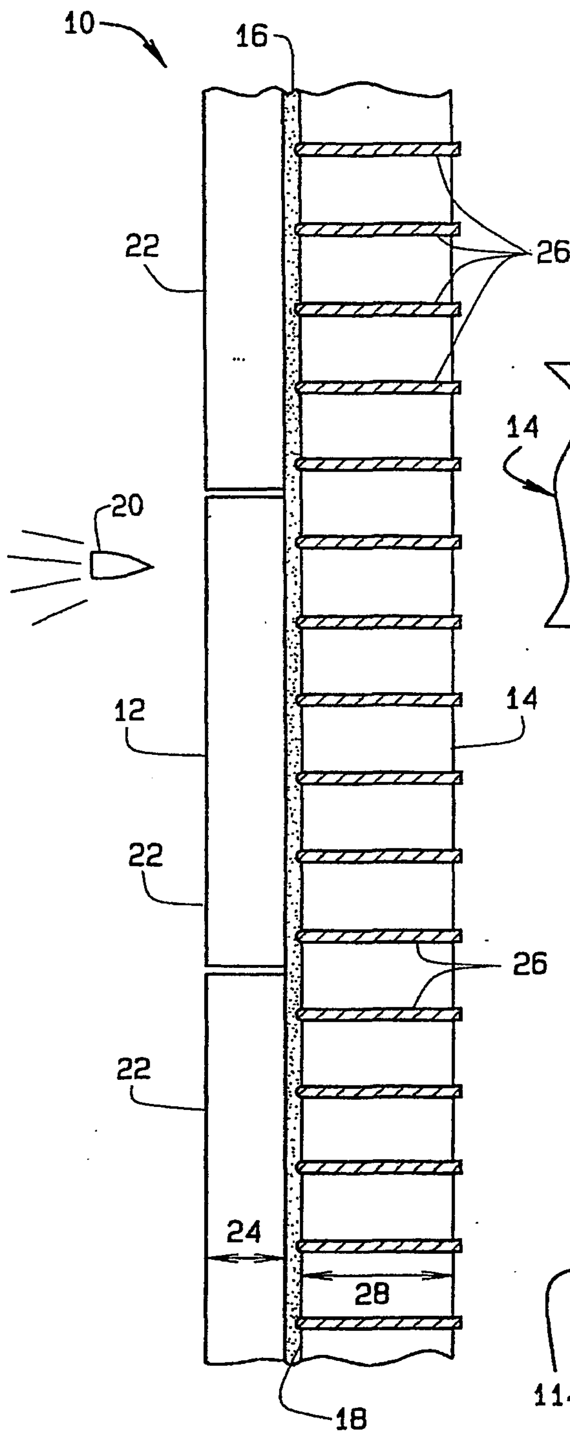

FIG. 1

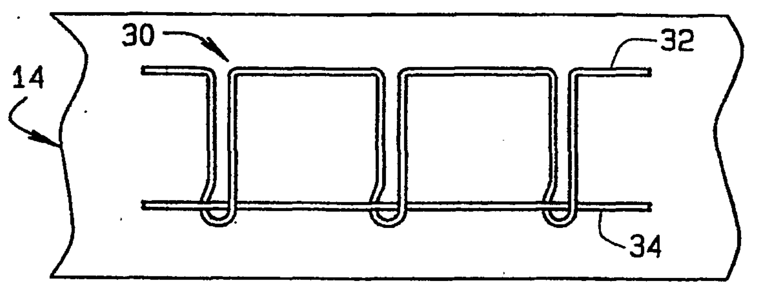

FIG. 2

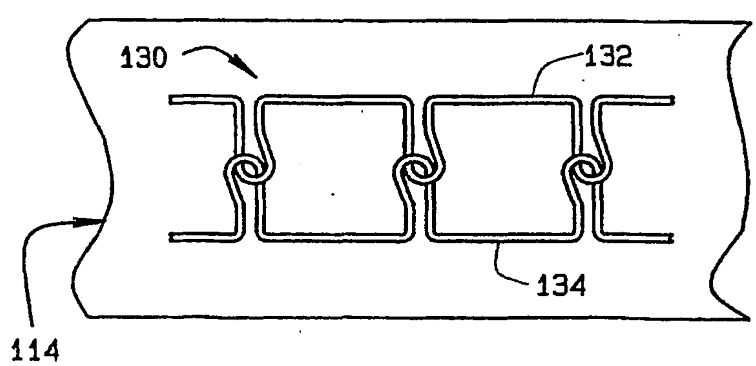

FIG. 3

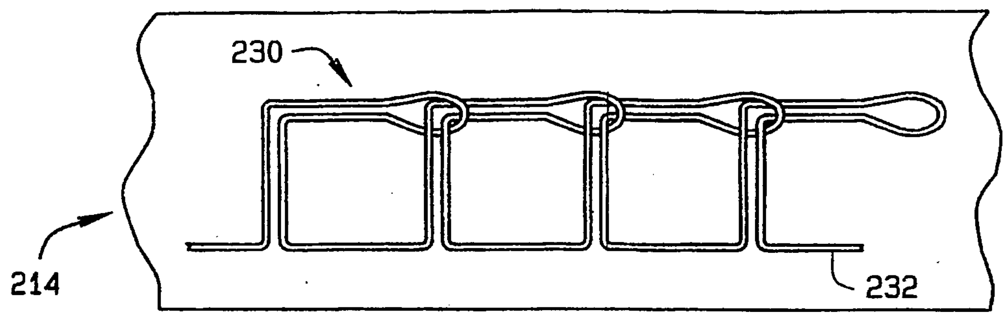
230
214
232

FIG. 4

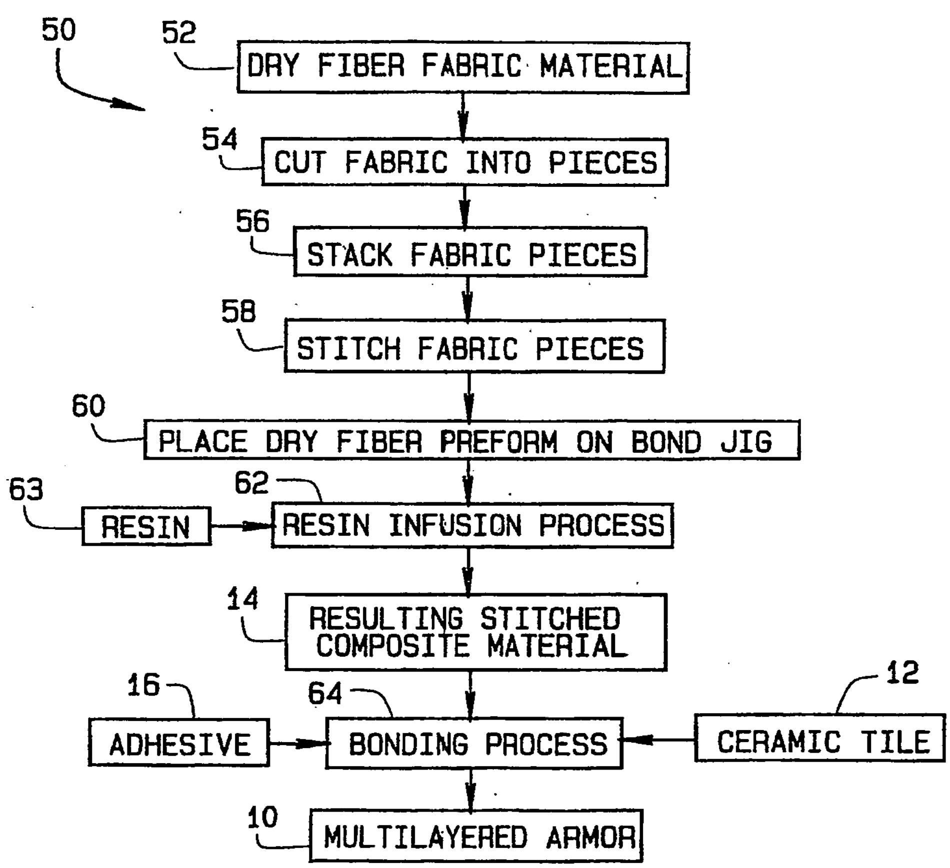
50
52 DRY FIBER FABRIC MATERIAL
54 CUT FABRIC INTO PIECES
56 STACK FABRIC PIECES
58 STITCH FABRIC PIECES
60 PLACE DRY FIBER PREFORM ON BOND JIG
63 RESIN
62 RESIN INFUSION PROCESS
14 RESULTING STITCHED COMPOSITE MATERIAL
16 ADHESIVE
64 BONDING PROCESS
12 CERAMIC TILE
10 MULTILAYERED ARMOR

FIG. 5